Greenhouse Gas Technology Verification Center

A USEPA Sponsored Environmental Technology Verification Organization

Testing and Quality Assurance QA Plan for the ANR Pipeline Company Parametric Emissions Monitoring System (PEMS)

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TABLE OF CONTENTS

APPENDIX

APPENDIX A – Field Data Log Forms and Data Acquisition System Outputs

ACRONYMS / ABREVIATIONS

ANR	ANR Pipeline Company
ATDC	After Top Dead Center
bhp	Brake Horsepower
^{o}BTDC	Before Top Dead Center
CEMS	Continuous Emissions Monitoring System
cfh	Cubic Feet Per Hour
CFR	Code of Federal Regulations
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DQO	Data Quality Objective
DP	Differential Pressure
EPA	United States Environmental Protection Agency
ETV	Environmental Technology Verification
ft^3	Feet Cubed
Ft-lbs	Foot-Pounds
gm	Gram
H_2O	Water
Hp	Horsepower
hr	Hour
inches Hg	Inches Mercury
KEA	Kilkelly Environmental Associates
KV	Kilovolt
Lb	Pounds
Mbtu	Million British Thermal Units
Msec	Milli second
NO_x	Nitrogen Oxides
O_2	Oxygen
PEMS	Parametric (also Predictive) Emissions Monitoring Systems
ppm	Parts Per Million
ppmvd	Parts Per Million Volume Drybase
PSIG	Pounds Per Square Inch Gauge
QA	Quality Assurance
RA	Relative Accuracy
RPM	Revolutions Per Minute
SCF	Standard Cubic Foot
SRI	Southern Research Institute
THC	Total Hydrocarbons
The Center	Greenhouse Gas Technology Verification Center
WC	Water Column
^{o} F	Degrees F

1.0 BACKGROUND AND INTRODUCTION

The Environmental Technology Verification (ETV) program was established by the United States Environmental Protection Agency (EPA) in response to the belief that there are many viable environmental technologies which are not being used for the lack of credible third-party performance testing. With the performance data developed under the program, technology buyers in the United States and abroad will be better equipped to make informed environmental technology purchase decisions. In late 1997, EPA selected Southern Research Institute to manage one of twelve ETV verification entities: The Greenhouse Gas Technology Verification Center (the Center). Eleven other ETV entities are currently operating throughout the United States conducting third-party verifications in a wide range of environmental media and industries.

In March of 1997, the Center met with members of the Executive Stakeholder Group. In that meeting, it was decided that the oil and gas industries were good candidates for third-party verification of methane mitigation and monitoring technologies. As a consequence, in June of 1998 the Center hosted a meeting in Houston, Texas with operators and vendors in the oil and natural gas industries. The objectives of the meeting were to: (1) gauge the need for verification testing in these industries, (2) identify specific technology testing priorities, (3) identify broadly acceptable verification and testing strategies, and (4) recruit industry stakeholders. Industry participants voiced support for the Center's mission, identified a need for independent third-party verification, and prioritized specific technologies and verification strategies. Since the Houston meeting, a 19 member Oil and Gas Industry Stakeholder Group was formed, vendors of GHG mitigation devices were solicited in several technology areas, and verification testing of six gas industry-related technologies are in various phases of evaluation.

Natural gas transmission companies often use large gas-fired IC engines to drive gas compressors that transport gas through the transmission network in the United States. A parametric emissions monitoring system (PEMS) for gasseous emissions from large gas-fired internal combustion engines, has been developed by ANR Pipeline Company (ANR) of Detroit, Michigan. The patented (US Patent #5,703,777) PEMS approach provides an alternative to instrumental continuous emissions monitoring systems (CEMS), and has a potential to be a more cost-effective approach. In addition to monitoring emissions of carbon dioxide (CO_2), carbon monoxide (CO), total hydrocarbons (including methane) (THC), oxygen (O_2), and nitrogen oxides (NO_x), the ANR PEMS provides feedback on engine operating conditions which influence continuous emissions. This may facilitate appropriate operator response to maintain operating conditions that result in lowered fuel consumption and emissions. The parametric approach to determining air emissions is provided for in 40CFR64, and with over 13,000 natural gas compressors operating in the United States alone, the potential applicability of this system is significant.

ANR Pipeline Company has requested ETV verification be conducted, and a test of the ANR PEMS is scheduled to begin in July 1999 on an engine located at an ANR compressor station. This Test Plan describes the technology to be tested, and outlines the Center's plans to conduct the verification in a field setting.

The ANR PEMS will be tested over a full range of normal and off-normal engine operating conditions, after which a draft Verification Test Report will be issued. There are two classes of verification parameters to be evaluated: (1) emission monitoring relative accuracy determinations, and (2) PEMS operational performance determinations. The seven verification parameters associated with these areas are listed below, along with a brief statement of the approach that will be used to assess each parameter.

Relative accuracy determinations: PEMS emission prediction values are compared to emissions measured directly by in-stack instruments

- CO_2 relative accuracy
- NO_X relative accuracy
- CO relative accuracy
- THC relative accuracy

PEMS operational performance: PEMS ability to respond to adverse engine operating conditions

- PEMS prediction capabilities during abnormal engine operation
- PEMS ability to respond to sensor failure
- PEMS diagnostic capabilities (using data from evaluations above)

The parameters listed above will be assessed through observation, collection and analysis of emissions data generated by the PEMS, comparative instrumental gas measurements, use of engine data logs, and evaluation of ANR-supplied data used to characterize engine operations. PEMS emission prediction performance capabilities will be assessed under normal engine operating conditions, and then challenged by simulating “poor’ engine performance episodes and evaluating PEMS emission predictions during these episodes. The PEMS ability to provide the information needed for plant personnel to identify, diagnose, and then rectify problems that may produce poor emission performance (e.g., actual poor engine operation or sensor failures) will be addressed during the evaluation of the first six verification parameters listed above.

The remainder of this document provides descriptions and explanations of the PEMS and the planned verification. The document is organized as follows:

- Section 2 provides an overview of PEMS principals and describes the ANR PEMS design, set-up, and operation;
- Section 3 describes the testing site;
- Section 4 discusses the verification parameters and approach;
- Section 5 describes the testing and analysis procedures to be used;
- Section 6 describes the data validation process and quality assurance goals;
- Section 7 provides a draft outline of the Verification Report;
- Section 8 presents the project team organization and schedule information;
- Section 9 outlines health and safety issues associated with this test; and
- Section 10, the Bibliography, provides references relevant to this Test Plan, including references for detailed, step-by-step procedures for the Reference Methods to be used.

Certain limitations to this test must be stated. First, this evaluation is not intended to characterize PEMS Relative Accuracy when the host engine is operating abnormally, although performance data will be collected during abnormal operating conditions. Also, this verification is not intended to represent all types of engines operating under a wide range of conditions; i.e., performance results are specific to the host site engine tested, and any extrapolation of these results to other engines and operating conditions should be carefully considered.

2.0 PEMS TECHNOLOGY DESCRIPTION

2.1. PRINCIPALS OF PEMS TECHNOLOGY

The PEMS approach to monitoring exhaust emissions is based upon establishing relationships between engine operating parameters, as determined by commonly used sensors, and exhaust emissions. As such, PEMS are fundamentally computerized algorithms that describe the relationships between operating parameters and emission rates, and which estimate emissions without the use of continuous emission monitoring systems.

2.2. ANR PEMS DESCRIPTION

The ANR PEMS is applicable to large gas-fired IC engines, and because different engines have unique operating characteristics, the parameterization of a PEMS is engine specific. Each engine produces unique relationships between emissions and engine operational functions, and the PEMS used in this verification contains relationships unique to the host site engine. These relationships are a function of engine speed and engine load (as torque), but other operational parameters are also used including: engine efficiency (calculated fuel consumption/actual fuel consumption), ignition timing, combustion air manifold temperature, and combustion air manifold pressure. Relative humidity is not applicable to reciprocating engines, so therefore is not an operational parameter being considered.

Figure 1 illustrates several important ANR PEMS prediction features. The figure indicates that engine speed and torque are primary determinants of emissions, and that with values for speed and torque, the "baseline" emissions for an engine are defined. Baseline emissions are representative of a normally functioning and well-tuned engine, but as engine operational changes occur, indicators of engine efficiency, ignition timing, air manifold temperature, and air manifold pressure are used to adjust emission values. Within the ANR PEMS, monitored and estimated values for these five key parameters are used to increase or decrease predicted emission from the baseline level as shown in Figure 1. Table 1 describes the engine sensors from which values for these operational parameters are derived. During the verification testing, the Center will not check the calibration of these individual engine sensors, but calibration records will be obtained from ANR and will be included in the final Verification Report.

Figure 2 illustrates general PEMS operational steps and outputs. As the figure shows, the ANR PEMS contains several different functionalities including the prediction of continuous emissions, the reporting of total emissions and high emission alarms/alerts, the monitoring of engine sensor performance, and the reporting of potential sensor malfunctions.

Figure 1. ANR PEMS Operational Features

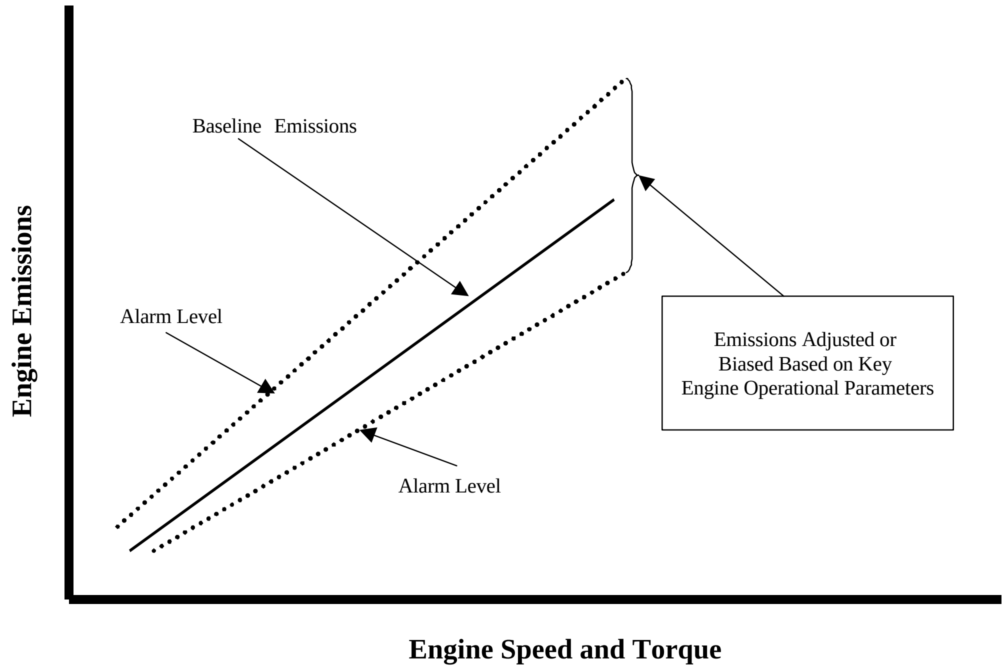
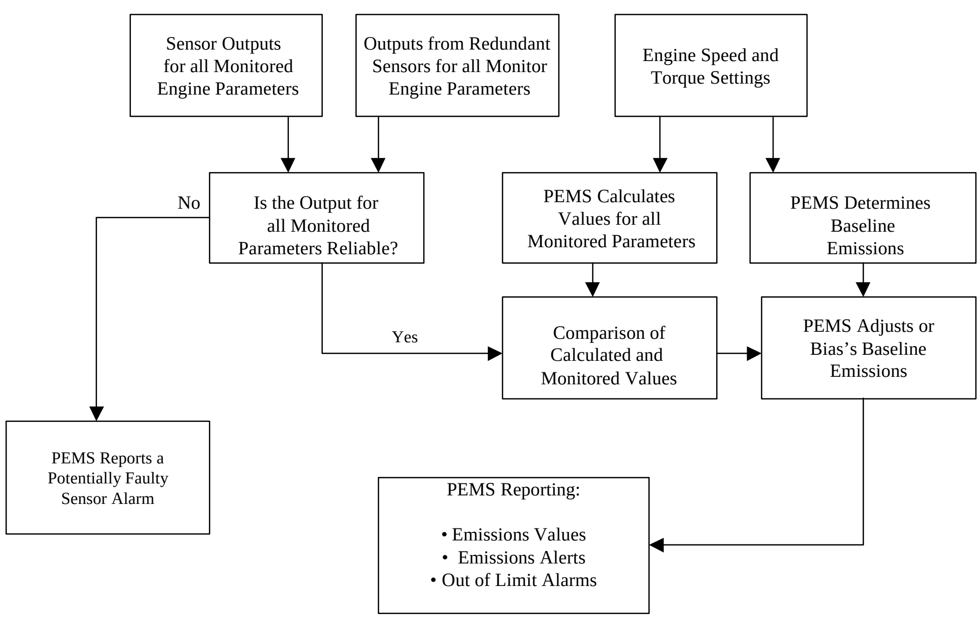


Figure 2. Simplified PEMS Diagram



As Figure 2 also suggests, the ANR PEMS uses redundant engine monitoring sensors. Redundant sensors are used for those engine parameters that ANR has found influence emissions the most including fuel flow, combustion air temperature, and combustion air pressure. This redundancy facilitates the assessment of sensor drift and the identification of failed or malfunctioning sensors.

Table 1. Engine Parameters/Sensors Used by PEMS

Sensor	Model	Specified Accuracy	Calibration Check	Operating Range
Ignition timing feedback	Altronic #DI-1401P	± 1% of full scale	Annual	45° BTDC to 45° ATDC
Fuel DP (flow)	Rosemount #1151DP-4-S-12-MI-B1 transducer	± 0.25%	Annual	0-100” wc
Fuel temperature	Rosemount #444RL1U11A2NA RTD	± 0.25%	Annual	0-125 °F
Air manifold pressure	Electronic Creations #EB-010-50-1-0-40/N transducer	± 0.25%	Annual	0-25 PSIG
Air manifold temperature	Rosemount 0068-F-11-C-30-A-025-T34 RTD	± 1%	Annual	0-150 °F

Alarms and alerts are set to give the engine operator knowledge when one or more key operating parameters is out of specification. These alarms/alerts are set by ANR personnel specifically for their desired operating rates. Key parameters that have alarm/alert functions include: efficiency (high and low), ignition deviation from set point, air fuel deviation from set point, and exhaust gas temperature absolute value (high and low). Three sensors have redundant units. These are: air manifold temperature, air manifold pressure, and fuel delta P.

2.3. ANR PEMS SET-UP ACTIVITIES

The PEMS will be set-up and parameterized in the field at the site described in Section 3. As a first step, the engine is determined to be well-tuned and operating normally, including all sensors. Once this is done, data are collected to support the development of emission relationships. This is done by first operating under a variety of normal engine speed and torque conditions while simultaneously measuring the emissions of NO_x, CO, O_2, THC, and CO_2. Emission measurements are collected with calibrated continuous emission monitors, and these data are used to determine baseline, or normal, emission relationships for various speed and torque conditions. Because small deviations in engine speed and torque can result in changes in engine operation and emissions, interpolation between the measured values is necessary and accomplished through linear regression techniques.

To build relationships which predict emissions at other than normal conditions, engine operation is forced to change by overriding automated engine control systems. This allows off-spec operations to be simulated and their impact on emissions characterized. Engine operating parameters varied in this step include combustion air temperature, combustion air pressure, engine operating efficiency (calculated fuel consumption/actual fuel consumption), and ignition timing. Each parameter is raised and then lowered from a normal condition until an alarm occurs (i.e., emissions exceed a specified limitation or engine efficiency has degraded to unacceptable levels). As the engine moves in and out of normal operation, continuous monitors simultaneously measure and record the emissions of NO_x, CO, O_2, THC, and CO_2.

The ANR PEMS develops relationships between all key operating parameters. From these relationships, emission levels are predicted when multiple operating parameters are outside of their individual set points. The PEMS determines and responds to the highest emission-level resulting from a particular combination of set point conditions. The PEMS defaults to the sensor that is indicating the higher NO_x emission rate.

ANR will complete the installation and set-up of the PEMS and establish acceptable correlation between engine operating conditions and actual emissions of the designated gasses to the atmosphere. Specific procedures necessary to establish these correlations and report emission values are fundamental to the PEMS, and are not an element of the performance verification testing to be conducted. An independent contractor working for ANR will conduct emission testing for the set-up process. The ANR test contractor, Mechanical Equipment Company of El Paso, Texas, will remain on site after the set-up process is complete, and will concurrently collect emissions data with the verification testing team in order to establish equivalency of the emissions data against which the PEMS was calibrated. Center staff will collect and evaluate the concurrent data from both parties. Should a significant discrepancy (greater than 10 percent) exist between the data collected, the cause of the discrepancy will be investigated and corrected prior to proceeding with the PEMS verification tests. As the test set-up is being performed, an assessment will be made to ensure that any other parameters that may be a factor are considered.

3.0 DESCRIPTION OF THE TESTING SITE

3.1. SITE SELECTION AND DESCRIPTION

The PEMS approach to exhaust emissions determinations requires engine specific verification of the PEMS to account for the design and operating characteristics of each engine type upon which it is installed. Thus, engine characteristics are not a significant restriction or limiting factor for the PEMS verification test. With this level of flexibility, ANR claims that the PEMS is appropriate to most types and sizes of internal combustion engines. This allowed a level of flexibility in site selection. The engine/compressor selected for this evaluation is shown in Figure 3. It is a reciprocating, 4-cycle internal combustion (IC) engine, utilizing natural gas as a fuel. The engine is an Ingersoll-Rand (model KVR-616: 16 cylinder, 6000 Hp), and is equipped with six reciprocating compressors. As with the engine selection, site location was somewhat flexible. The primary area of concern was any limitation on engine operation due to extremes of weather. Accordingly, extremes of environment, very hot or very cold, were avoided. The site selected is a mid-western gas transmission station operated by ANR Pipeline Company.

Based on data from ANR Pipeline staff, measurements collected during several compliance tests suggest that the maximum and expected emission levels will be:

- CO_2 – 7% Max., 5.8% anticipated
- NO_x – 2500 ppm Max., 2027 ppmvd anticipated
- CO - 350 ppm Max., 226 ppmvd anticipated
- THC - 900 ppm Max., 756 ppmvd anticipated
- O_2 – 13% Max., 11.7% anticipated

Automated data acquisition systems exist at the plant which coordinate, collect, and record engine operating variables monitored by various engine sensors. The system samples each variable at 5-second intervals, and can report/record one-minute average values. To be consistent with the concentrations measured by the CEMS, 30-second average values will be collected and stored. Digital files containing 30-second average values for each monitored parameter will be collected and stored throughout the sampling period. Values relevant to the verification will be reported in the final Verification Report. The parameters monitored include those listed below.

- Speed – (Measured digitally) - RPM
- Torque, Calculated – (Derived from compression work) – Ft-lbs
- Torque, Fuel – (Derived from fuel consumption) – Ft-lbs
- Air Manifold Pressure – (Charge pressure going into the cylinder)– inches Hg
- Exhaust Manifold Pressure – (Pressure in the common exhaust manifold, post ports and pre turbocharger) – inches Hg
- Ignition Timing – (Measured value of #1 cylinder ignition and compared to computer assumed value) - ^{o}BTDC
- Efficiency – (Calculated fuel divided by actual fuel) - %
- Air Manifold Temperature – (Charge temperature going into cylinder) - ^{o}F
- EGT Std. dev. – Exhaust gas temperature, standard deviation. (Usually taken at each cylinder port. Infers good “balance” all the cylinders producing the same amount of power) - ^{o}F
- Fuel Flow – (Orifice type fuel measurement system using redundant DP sensors. Is the basis for calculating efficiency.) – inches Hg
- Turbocharger Speed - RPM
- Turbocharger Outlet Air Temperatures – (Both pre and post intercooler)- ^{o}F
- Turbocharger Inlet and Outlet EGTs – Exhaust gas temperature in and out of the turbocharger - ^{o}F
- Turbocharger “bypass” – (A proportional valve around the hot wheel of the turbocharger, which controls Air to Fuel ratio of the engine) % Open
- Hickok Ignition Monitor – (Measures break down voltage and glow duration of each spark plug) – kV & Msec.
- Vibration – (Multi-points)
- Fuel Manifold Pressure - PSIG
- Oil & Coolant Temperatures - ^{o}F
- Suction & Discharge, Pressure & Temperatures – PSIG & ^{o}F

Figure 3. Photograph of Test Engine

4.0 VERIFICATION PARAMETERS AND THEIR DETERMINATION

A test of the ANR PEMS is scheduled for mid July 1999, and will be carried out on a large gas-fired IC engine located at an ANR compressor station in the Midwestern United States. This section describes the analysis methods that will be used to address each of the seven verification parameters listed below. Specific testing strategies and matrices are presented, and key calculations and instrumental testing methods planned for use are identified. Section 5 describes the instrumental methods planned for use in the field.

The ANR PEMS will be tested over a full range of normal and off-normal operating conditions, during which two classes of verification parameters will be evaluated. In the first class, PEMS emission prediction values will be compared to emissions measured directly by instrumental methods, allowing the determination of the Relative Accuracy for each gas reported by the PEMS. In the second class, a number of important PEMS performance features will be evaluated including its ability to respond to abnormal engine operation conditions and failed or drifting sensors. PEMS ability to facilitate the identification and mitigation of abnormal engine operation will also be examined.

The seven verification parameters listed below are described individually in the following sections.

Relative accuracy determinations:

- CO_2 relative accuracy
- NO_X relative accuracy
- CO relative accuracy
- THC relative accuracy

PEMS operational performance:

- PEMS prediction capabilities during abnormal engine operation
- PEMS ability to respond to sensor failure
- PEMS diagnostic capabilities (using data from evaluations above)

4.1. RELATIVE ACCURACY DETERMINATIONS

As the PEMS approach to air emissions monitoring is a new technology, it is in limited use. As such, formalized performance demonstration procedures specific to PEMS have not been established to date.

Instrumental monitoring systems have been developed to the level that they are a primary means for monitoring gasseous emissions from industrial processes for regulatory compliance purposes. This recognition has led to EPA's development of Performance Specification Test procedures to confirm the precision and accuracy of instrumental monitoring systems. With some augmentations, these EPA Performance Specification Tests can also be used to determine PEMS performance, and as such, EPA's Performance Specification Tests are the primary basis used to assess the ANR PEMS monitoring performance. EPA has prepared example specifications and evaluation procedures for assessing PEMS performance (Emission Measurement Center, USEPA), and these guidelines have been followed here.

EPA's Performance Specification Tests require the use EPA Reference Test Methods to collect actual emissions data for comparison with PEMS values. The list below identifies the individual Performance Specification Tests planned for use, and their accompanying Reference Test Method.

- Performance Specification Test 2 for NO_x: Reference Method 7E
- Performance Specification Test 3 for CO_2 & O_2: Reference Method 3A
- Performance Specification Test 4 for CO: Reference Method 10A
- Performance Specification Test 8 for THC: Reference Method 25A

In general, PEMS emission predictions will be compared with EPA Reference Method values. These comparisons will be made after PEMS and CEMS values are placed on a common basis (e.g., common moisture and temperature), and after each have been carefully time-matched. To facilitate time-matching, synchronization of the PEMS and EPA Reference Method data acquisition clocks will be done daily, and sampling system lags associated with the Reference Method Sampling Train response time will be measured and integrated into the time-matching. Reference Method 19 will be used to relate measured gas concentrations to mass rates.

For each of the five gasses listed above, the parameter that will be used to represent the result of the PEMS/Reference Method comparison is Relative Accuracy. Relative Accuracy will be calculated in accordance with the four-step process outlined below.

First, calculate the arithmetic mean of the difference, d, for all runs conducted as in Equation 1 below:

$$\overline{d} = \frac{1}{n}\sum_{i=1}^{n} d_i \qquad (1)$$

Where:

n = number of runs
d_i = difference between Reference Method and PEMS output for a run

Second, calculate the standard deviation associated with all runs, Sd, as shown in Equation 2 below:

$$S_d = \left[\frac{\sum_{i=1}^{n} d_i^2 - \frac{\left[\sum_{i=1}^{n} d_i\right]^2}{n}}{n-1} \right]^{\frac{1}{2}} \qquad (2)$$

Third, calculate the 2.5 percent error confidence coefficient (one-tailed), cc, as shown in Equation 3 below:

$$cc = t_{0.975} \frac{S_d}{\sqrt{n}} \qquad (3)$$

Where: $t_{0.975}$ = t-value (see Table 2).

TABLE 2: t-Values					
n*	$t_{0.975}$	n*	$t_{0.975}$	n*	$T_{0.975}$
2	12.706	7	2.447	12	2.201
3	4.303	8	2.365	13	2.179
4	3.182	9	2.306	14	2.160
5	2.776	10	2.262	15	2.145
6	2.571	11	2.228	16	2.131

- The values in this table are already corrected for n-1 degrees of freedom. Use n equal to the number of individual values.

And finally, fourth, calculate the Relative Accuracy, RA, for all runs as shown in Equation 4 below:

$$RA = \left[\left| \overline{d} \right| + \left| cc \right| \right] \frac{100}{\overline{RM}} \qquad (4)$$

Where: $\left|\bar{d}\right|$ = Absolute value of the mean differences (from Eq. 1)

$\left|cc\right|$ = Absolute value of the confidence coefficient (from Eq. 1)

RM = Average Reference Method value

Recall that engine speed and torque are primary determinants of engine emissions. Collection of the emissions and other data needed to perform Relative Accuracy determinations will occur while the engine operates under normal speed and torque conditions, and when it is in a well-tuned state. Engine operators at the site will determine when these conditions are met, and thus, when Relative Accuracy testing can begin. The test engine normally operates within a range of torque values of between 75 to 100 percent of capacity. To achieve these torque values, engine speed (RPM) is maintained in the range of 75 to 100 percent of maximum. Although the engine/compressor is capable of operating with loads and speeds as low as 50 percent, operation at loads and/or speeds of less than 70 percent occurs only during start-up or severe process interruption. This engine operates at loads/speeds of 85 percent to 100 percent approximately 90 percent of its operating time. The other ten percent of the time it operates at 70 percent to 85 percent of load/speed.

A series of normal operating conditions have been specified for the Relative Accuracy determinations, and these are shown in the testing matrix presented in Table 3. The individual speed/load values in the matrix are nominal values that will be attempted in the field, but slight variations may occur as a result of compressor demand and other conditions occurring during testing. A series of 3 runs will be conducted at each operating condition, and each run will occur for a 21 to 30 minute period after stable emissions readings have been observed via the Reference Method monitors.

Table 3. Relative Accuracy Test Matrix[1]

Nominal Engine Speed %	Nominal Engine Load (%)		
	50 – 75	75 – 90	90 – 100
50 – 75	Not normal	Not normal	Not normal
75 – 90	Not normal	3 runs	3 runs
90 – 100	Not normal	3 runs	3 runs

[1] All runs will be a minimum of 15 minutes after stable operating conditions are attained.

Emission data from the Reference Methods and the PEMS will be complied for CO_2, NO_x, THC, and CO, under the conditions above.   Results and relative accuracys will be presented on both a concentration basis (ppm or percent) and for the pollutants, on an emission factor basis (gram/brake horsepower-hour). This will result in two sets of results with 12 results each.

In accordance with EPA Performance Specification Test procedures, a minimum of nine runs are required for use in determining Relative Accuracy, so up to 3 may be removed (although all 12 may also be used). If any of the 12 runs are eliminated, it will be done to eliminate runs that contain a high degree of poor or unexplainable quality data. In no case will all three runs from one operating condition be eliminated. Runs exhibiting a high difference between the Reference Method and PEMS emissions outputs may also be eliminated keeping with this often used practice in Relative Accuracy Tests for CEMS. The individual runs selected may vary, depending on the gas being evaluated, but results from all 12 runs will be provided in the final Verification Report. Relative Accuracys that are 20 percent or less are generally considered acceptable for CEMS used for regulatory purposes.

The procedures and instrumentation associated with the execution of specific Reference Methods and other sampling tasks are described later in Section 5.

4.2. OPERATIONAL PERFORMANCE EVALUATIONS

Operational performance evaluations will be conducted to assess the PEMS ability to respond to sensor drift, failure, and abnormal engine operating conditions. Both are discussed individually in the following three sections. Data from these two evaluations can be used to assess how PEMS outputs and alarms may be used to identify and diagnose engine/sensor operational problems.

4.2.1. PEMS Prediction Capabilities During Abnormal Engine Operation

In Section 4.1, procedures for evaluating the PEMS under normal engine operating conditions were described. These conditions are where the engine operates most often, but mechanical engine changes, changes in fuel properties, and changes in ambient conditions can change engine performance and emissions relative to normal operation. To examine how the ANR PEMS responds to off-normal engine operating conditions, a series of tests will be conducted while physically perturbing key engine operating characteristics. According to ANR, the most significant engine operating features impacting emissions are pollutant specific but from a general perspective, the most significant parameters, in approximate order, are: (1A) air manifold pressure, (1B) exhaust manifold pressure, (2) ignition timing, (3) engine efficiency, (4) air manifold temperature, (5) exhaust manifold temperature, and (6) relative humidity. The operating parameters planned for perturbation include all those parameters above which can be physically perturbed on the engine. This excludes ambient humidity, where perturbations can not be easily simulated, and exhaust gas pressure and temperature, which can not be altered in a predictable manner. The parameters to be varied, the physical methods planned to vary them, and the measurements planned for each condition are summarized below.

- Combustion air manifold temperature and pressure – Air manifold temperatures will be varied by manually changing the temperature setting, causing the engine to increase or decrease combustion air flow through the heat exchanger (turbocharger jacket). Both high and low temperatures that are close to the upper and lower air temperature alarm levels will be established, and runs of 21 to 30 minute duration will be started once the conditions are reached, and measured pollutant concentrations have become relatively stable. manifold pressure changes will be accomplished by increasing and decreasing combustion air flow.

- Engine efficiency – Engine efficiency is a function calculated from: calculated fuel consumption/actual fuel consumption. Overriding the engine computer and manually changing the engine horsepower value will vary this operating parameter. This will, in-turn, cause the engine to change fuel flow without a true need for a fuel change (i.e., the actual demand on the engine is changed). With the engine consuming non-optimal fuel, efficiency will be changed. By increasing and decreasing the horsepower setting, efficiency will be raised to an optimum level, and then reduced to a point where the engine efficiency or some other related engine alarm occurs. Runs of 21 to 30 minute duration will be started once each condition is reached, and measured pollutant concentrations are relatively stable.

- Ignition timing – Ignition timing will be manually adjusted to vary this operating parameter. As above, values just short of upper and lower alarm values will be established, and 21 to 30 minute runs will be conducted at both conditions.

Depending on the engine torque and speed, emission changes occurring as a result of changes in the operating parameters above may vary in their significance. Thus, the evaluations above will be conducted under a number of different torque and speed conditions, resulting in the execution of 24 individual runs. Evaluation of off-normal operations will focus on those speed and torque operating ranges that occur most often for the engine. A matrix summarizing the tests planned is presented as Table 4. Guidelines for the establishment of low and high alarm conditions required for each test are shown in Table 4a.

The adequacy of the PEMS response to an off-normal condition will be determined by comparing the concentration obtained from the Reference Method with the concentration obtained from PEMS. The difference and percent difference between these two values will be presented in the Verification Report.

Table 4. Off-Normal Engine Operating Conditions to be Tested[1]

Operational Parameter/Alarm Condition		**Nominal Engine Speed/Torque (%)**		
		100/100	**75/100**	**100/75**
Efficiency	High	X	X	X
	Low	X	X	X
Ignition Timing	High	X	X	X
	Low	X	X	X
Air Manifold Temperature	High	X	X	X
	Low	X	X	X
Air Manifold Pressure	High	X	X	X
	Low	X	X	X
	Low	X	X	X
	Low	X	X	X

X = 1 run. All runs will be a minimum of 15 minutes after stable conditions are attained.

Table 4a. Engine Sensor Alarm and Alert Levels

		Alert	**Alarm**
Efficiency	High	105%	110%
	Low	95%	90%
Ignition Deviation from Set Point		0.5%	1.0%
Air Manifold Temperature (Redundant Transmitter Deviation)		2 ^{o}F	4 ^{o}F
Air Manifold Pressure Deviation from Set Point		0.3 psi	0.5 psi
Air Manifold Pressure Redundant Transmitter Deviation		0.2 psi	0.3 psi

4.2.2. PEMS Response to Sensor Failure

This will be the first test conducted on-site to ensure the PEMS responds appropriately to changes in engine sensor inputs. Objectives of this test are to demonstrate the performance of PEMS when engine sensor failure occurs, and to document PEMS ability to identify potentially failed engine sensors.

ANR has designed the PEMS to provide conservative emission predictions when sensor drift or failure occurs. When failure occurs, and dual sensors are used to monitor the engine parameter, the PEMS uses the sensor input that results in the highest predicted emission rate. If the predicted emissions are higher than a pre-set emission level; usually the maximum permitted emissions for the operating engine, the PEMS alarms. When sensor failure occurs, operators use the PEMS alarm, if the alarm level has been reached and/or the sensor alarms on the engine control system, to diagnose and resolve failed sensors. For engine parameters that do not have redundant sensors (i.e., energy efficiency and ignition timing), erroneous readings from failed sensors can also result in high emissions indications and alarms at some point within the failure period.

The performance of PEMS during engine sensor failure will be examined by verifying PEMS responses to simulated sensor failures. To accomplish this, the PEMS emission predictions will be documented while artificially (electronically) simulating engine sensor outputs that correspond to a failed sensor. The process will start by establishing steady state engine operation at torque and speed levels that are within 75 to 100 percent of maximum. The steady-state CEMS and PEMS concentrations prior to sensor perturbation will then be recorded to establish comparability. Next, sensor perturbation will be simulated by manually adjusting sensor output signals for each PEMS sensor including: ignition timing, exhaust manifold pressure, engine efficiency (fuel flow related sensors), air manifold temperature, and air manifold pressure. Sensors will be perturbed one at a time, and each will be changed by slowly adjusting the sensor output signal until the transmitter alarm level is reached. Throughout this perturbation period, the data below will be recorded.

- Default or conservative emission value used by PEMS,
- Perturbed sensor signal values,
- All other sensor values,
- PEMS concentrations and emission rates for all pollutants,
- Alarm/alert conditions reported by the PEMS and engine computer, and
- Reference Method concentrations and emission rates for all pollutants.

These data will be used to verify how PEMS predictions change as sensors drift toward the alarm level, and, if appropriate information is available for operators to identify a failed sensor condition. The simultaneous CEMS data will allow a direct comparison of actual emissions with PEMS emissions, and will demonstrate how the two values diverge as sensor failure approaches. The entire procedure will be repeated for low- and high-level alarm regimes, and with all five sensors. A total of 10 tests will be conducted with run durations of 21 to 30 minutes, or as needed to achieve stable PEMS concentrations at multiple sensor settings (3 sensor setting or higher).

Finally, to assess the impact of multiple failed sensors, the procedure above will be repeated for pairs of simulated sensor failures. Specifically, two sensors monitoring different engine parameters (e.g., combustion air temperature and exhaust pressure) will be artificially perturbed to the sensor alarm level. As above, the values listed earlier will be recorded, then the procedure will be repeated for all combinations of sensor pairs and low/high alarm levels. This will result in the execution of 20 individual runs.

4.2.3. Assessment of PEMS Diagnostic Capabilities

Data collected as described in the previous two sections (Sections 4.2.1 and 4.2.2) will be used to assess how well PEMS provides diagnostic information that engine operators can use to identify and rectify engine operating and sensor problems that may negatively impact emissions.

Section 4.2.1 described how data would be collected when actual engine malfunctions are occurring. These data will be used to assess PEMS ability to warn of poor engine performance and subsequent emission increases. For example, when efficiency perturbations are simulated by increasing horsepower as described earlier, PEMS alerts and alarms for parameters such as efficiency, fuel flow, and fuel temperature could be indicative of engine efficiency problems. The occurrence of these alarms and alerts, and other indications that may assist in diagnosing engine efficiency (e.g., other engine system data), will be recorded as described earlier, and will be evaluated with the assistance of ANR engine operators. These data and findings will be summarized in the final Verification Report, but any conclusions will be qualified, since the methods chosen to perturb engine operation were chosen for convenience, and other perturbation mechanisms could cause different PEMS alarm responses. For example, high humidity could impact efficiency, just like the planned horsepower adjustment, but in this case, different PEMS or engine alarms may occur.

PEMS alarms and alerts recorded under the sensor failure analyses described in Section 4.2.1 will be used to qualify how well PEMS alerts operators to the existence of failed sensors, or the possibility that a sensor is drifting significantly.

5.0 FIELD TESTING PROCEDURES

5.1. OVERVIEW

The test procedure described in this section has been developed to provide the framework for testing the ANR PEMS during both normal and off-normal engine operation. It is based upon EPA Performance Specification Test guidelines for CEMS and the document "Example Specifications and Test Procedures for Predictive Emission Monitoring Systems" provided by EPA's Emission Measurement Center (Emission Measurement Center, 1999).

The test procedures to be utilized in this verification are Federal Reference Methods. Reference Methods are well documented in the Code of Federal Regulations, include detailed procedures, and generally address the elements listed below (40CFR60, Appendices A and B).

- Applicability and principle
- Range and sensitivity
- Definitions
- Measurement system performance specifications
- Apparatus and reagents
- Measurement system performance test procedures
- Emission test procedure
- Quality control procedures
- Emission calculations
- Bibliography

Each of the selected methods utilizing an instrumental measurement technique includes performance-based specifications for the gas analyzer used. These performance criteria cover span, calibration error, sampling system bias, zero drift, response time, interference response, and calibration drift requirements.

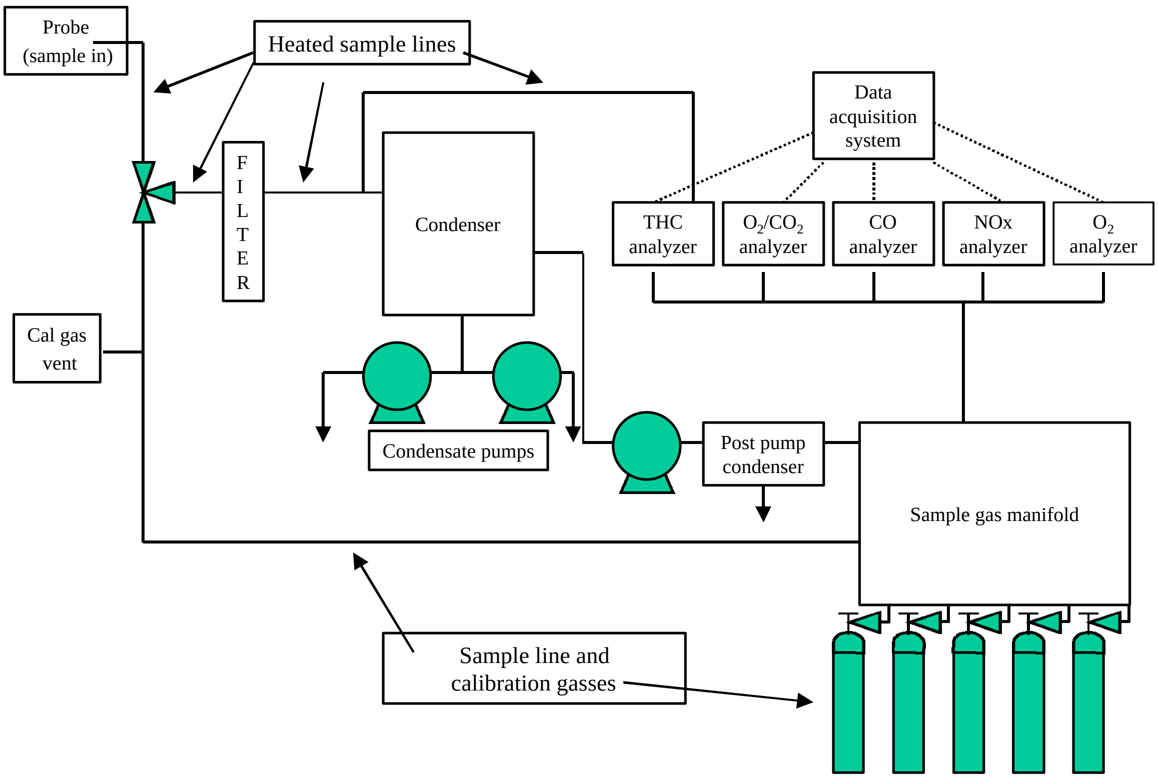
An overview of each test method planned for use is presented in this section, with emphasis on the type of monitors used, the monitor range, the sampling system configuration, and general calibration plans. The entire method reference will not be repeated here, but will be available to site personnel during testing, and can be viewed in the Code of Federal Regulations (40CFR60, Appendix A). Field log forms that will be used to conduct calibrations and other field activities are presented in Appendix A. CEMS output formats and summaries are presented later in Section 5.3.

5.2. SAMPLE HANDLING AND TESTING METHODS

5.2.1. Sample conditioning and handling

A schematic of the sampling system to be used is presented as Figure 4. In order for some of the instruments used to operate properly and reliably, the flue gas must be conditioned prior to introduction into the analyzer. The gas conditioning system is designed to remove water vapor and/or particulate from the sample. All interior surfaces of the gas conditioning system are made of stainless steel, Teflon™, or glass to avoid/minimize any reactions with the sample gas components. Gas is extracted from the gas stream through a heated stainless steel probe, filter, and sample line and transported to two ice bath condensers on each side of the sample pump. The condensers remove moisture from the gas stream. The clean, dry sample is then transported to a flow distribution manifold where sample flow to each analyzer is controlled. Calibration gasses can be routed through this manifold to the sample probe by way of a Teflon™ line. This allows calibration and bias checks to include all components of the sampling system. The distribution manifold also routes calibration gasses directly to the analyzer when linearity checks are made on each of the analyzers.

Figure 4. Gas Sampling and Analysis System



The system response time between sample collection and actual monitoring (i.e., the system response time) will be determined to ensure that a time-matched comparison of PEMS and CEMS outputs are made. The sampling system response time will be measured at the beginning of field testing. The procedure will include the following stepwise process: (1) initiate a flow of zero concentration calibration gas at the probe and wait for steady-state readings to occur, (2) introduce a high concentration calibration gas while simultaneously recording the start time, (3) record the time at which the gas concentrations due to the step increase are at 95 percent of their expected level, and (4) repeat the procedure going from high to zero and record the system response time as the longer of the two.

5.2.2. Calibrations

Calibrations will be conducted on all monitors using Protocol No. 1 calibration gasses. Protocol No. 1 gasses comply with requirements for traceability to the National Institute of Standards and Technology.

Each monitor will be calibrated with a zero concentration gas. In addition, each will be calibrated with a suite of gasses, selected to cover the monitor operating ranges specified later in Section 5. The NO_x, CO_2, and O_2 monitors will be calibrated with two additional gas concentrations each. One concentration will be 40 percent to 60 percent of span and one will be 80 percent to 100 percent of span. Maximum and actual concentrations anticipated for the test engine can be found in Section 3. The CO and THC monitors will be calibrated with three additional gas concentrations. For CO, the concentrations will include one each at approximately 30 percent, 60 percent, and 90 percent of span. For THC methane will be used, consistent with the basis PEMS uses to report THC. The calibration concentration ranges for THC includes the following: 25 to 35 percent, 45 to 55 percent, and 80 to 90 percent of span.

All monitor calibrations will be conducted daily, before sampling begins. Calibrations will start by routing calibration gasses directly to each monitor, and then adjusting the monitors to read the appropriate calibration gas values. After adjustments are made to the analyzers, a final linearity test is conducted by introducing each gas to the analyzers and recording responses while making no adjustments. Acceptable results are within two percent of span for each gas. Following this and after each test run, zero concentration and mid-span gasses will be passed through the entire sampling system, and the values that are measured will be recorded. Differences between the initial calibration and these system calibrations will be used to determine system bias and drift values for each run and analyzer drift over the duration of each run. These bias and drift values are used to adjust CEMS concentrations after field operations are completed.

Regarding engine sensor calibrations, SRI will obtain for the report copies of the most recent calibration records for all of these sensors.

5.2.3. Reference Method 3A – Determination of Oxygen & Carbon Dioxide Concentrations

For carbon dioxide and oxygen, a continuous sample will be extracted from the emission source and passed through instrumental analyzers. For determination of CO_2 a Milton Roy 3300 nondispersive infrared (NDIR) analyzer will be used. NDIR measures the amount infrared light that passes through the sample gas versus a reference cell. As CO_2 absorbs light in the infrared region, the light attenuation is proportional to the CO_2 concentration in the sample. Based on the site-specific data contained in Section 3, the CO_2 monitor range will be set at or near 0 to 20 percent.

Oxygen will be analyzed using a Teledyne 320A fuel cell-analyzer. This analyzer uses electrolytic concentration cells that contain a solid electrolyte to enhance electron flow to the O_2 as it permeates through the cell. The fuel-cell technology used by this instrument determines levels of O_2 based on partial pressures. The electrode is porous (zirconium oxide) and serves as an electrolyte and as a catalyst. The sample side of the reaction has a lower partial pressure than the partial pressure in the reference side. The current produced by the flow of electrons is directly proportional to the O_2 concentration in the sample. Based on the site-specific data contained in Section 3, the O_2 monitor range will be set at or near 0 to 25 percent.

5.2.4. Reference Method 7E - Determination of Nitrogen Oxides Concentration

Nitrogen oxides will be determined on a continuous basis, utilizing a Thermo Environmental Model 10S chemilumenescence analyzer. This analyzer catalytically reduces nitrogen oxides in the sample gas to NO. The gas is then converted to excited NO_2 molecules by oxidation with O_3 (normally generated by ultraviolet light.) The resulting NO_2 emits light ("lumenesces") in the infrared region. The emitted light is measured by an infrared detector and reported as NOx. The intensity of the emitted energy from the excited NO_2 is proportional to the concentration of NO_2 in the sample. The efficiency of the catalytic converter in making the changes in chemical state for the various nitrogen oxides is checked as an element of instrument set up and checkout.

Based on the site-specific data contained in Section 3, the NO_x monitor range will be set at or near the 0 to 500 ppm range.

5.2.5. Reference Method 10A - Determination of Carbon Monoxide Concentration

For Reference Method 10A, a Thermo Environmental Model 48 gas filter correlation analyzer utilizing an optical filter arrangement will be used. This method provides high specificity for CO. Gas filter correlation utilizes a constantly rotating filter with two separate 180-degree sections (much like a pinwheel.) One section of the filter contains a known concentration of CO, and the other section contains an inert gas without CO. The sample gas is passed through the sample chamber containing a light beam in the region absorbed by CO. The sample is then measured for CO absorption with and without the CO filter in the light path. These two values are “correlated”, based upon the known concentrations of CO in the filter, to determine the concentration of CO in the sample gas.

Based on the site-specific data contained in Section 3, the CO monitor range will be set at or near the 0 to 2,500-ppm range.

5.2.6. Reference Method 25A - Determination of Total Gasseous Organic Concentration

Total hydrocarbons vapors in the exhaust gas will be measured using a JUM Model VE-7 flame ionization analyzer. This method passes the sample through a hydrogen flame. The intensity of the resulting ionization is amplified and measured and then converted to a signal proportional to the concentration of hydrocarbons in the sample. Unlike the other methods, the sample stream going to the JUM analyzer does not pass through the condenser system, so it can be kept heated until it is analyzed. This is necessary to avoid loss of the less volatile hydrocarbons in the gas sample. Because all combustible hydrocarbons are being analyzed and reported, the emission value must be calculated to some base (methane or propane). The calibration gas for THC will be either methane or propane; which ever is consistent with the basis on which PEMS reports THC values.

Based on the site-specific data contained in Section 3, the THC monitor range will be set at or near the 0 to 1,000 ppm range (as methane).

5.2.7. Reference Method 19 - Determination of Emission Rates

Method 19 provides procedures for converting concentration values of various flue gasses to emission rate values. This is accomplished by determining the flow rate of the flue gas and then calculating the emission rate from the concentration and volume data. The fundamental principle of this method is based upon “F factors”. F factors are the ratio of combustion gas volume to the heat content of the fuel. F factors are calculated as a volume/heat input value, (e.g., standard cubic feet per million Btu). This method applies only to combustion sources for which the heating value for the fuel can be determined. The F factor can be calculated from either CO_2 or O_2 values, on either a wet or dry basis, as dictated by the measurement conditions for the gas concentration determinations. This method includes all calculations required to compute the F factors and guidelines on their use. The F factor for natural gas will be calculated from ANR supplied pipeline gas quality measurements (elemental analyses and heat contents). ANR monitors pipeline gas quality and heat content daily using a calibrated gas chromatograph.

Two sets of emission rates will be determined based on pollutant concentration values supplied by both the PEMS and CEMS. Other parameters include “F factors” determined from the flue gas composition and ANR supplied fuel quality data, fuel flow measured by ANR’s fuel flow monitoring system (pressure and temperature based), and calculated engine brake horsepower (calculated by ANR from engine speed and torque readings). The step-by-step calculations involved are listed below.

Step 1. Calculate pounds of pollutant per million BTU of heat input.
Lb/Mbtu = concentration from CEMS or PEMS converted to mass basis using molecular weights (Lb/scf) x f-factor from above (scf/Mbtu)

Step 2. Calculate the engine heat consumption rate in million BTU per hour.
Mbtu/hr = fuel rate determined from AGA-3 flow meter and temperature gauge (cfh) x fuel heating value (Mbtu/ft^3)

Step 3. Calculate the pounds per hour of pollutant.
Lb/hr = Lb/Mbtu (from step 1) x Mbtu/hr (from step 2)

Step 4. Calculate the grams per brake horsepower hour (bhp-hr) using ANR supplied bhp values.
gm/bhp-hr = Lb/hr (Step 3) x 453.59 gms/Lb = gm/hr /// gm/hr / bhp = gm/bhp-hr

5.3. DATA ACQUISITION

Output from each of the instruments will be transmitted to a personal computer-based data acquisition system. This system receives signals from all of the instruments every two seconds, and time integrates those values over a pre-specified averaging period. During all tests, a 30-second averaging period will be used for each monitored parameter, and these values will be stored for later analysis and reporting purposes. Average values will also be determined over the time associated with each run, and these values will be stored and used to determine run-average emissions for Relative Accuracy and other determinations. Excel spreadsheets will be used to calculate calibration results, and make corrections to the data for calibration, system bias, and drift values.

Data will also be collected on engine performance parameters, and these data will be provided by ANR’s data acquisition system. These data will be needed to calculate some verification parameters, identify alarm/alert conditions, and interpret verification results. Data will be recorded at 30-second intervals, and the specific parameters collected and stored are described in Section 3.

6.0 DATA VALIDATION AND QUALITY

6.1. DATA VALIDATION

Calibrations and quality control checks for each measurement were presented in Section 5. Upon review, all data collected will be classified as valid, suspect, or invalid. In general, valid results are based on measurements that meet data quality goals, and that were collected when an instrument was verified as being properly calibrated.

Often anomalous data are identified in the process of data review. All outlying or unusual values will be investigated daily in the field using test records, test crew and engine operator interviews, and log forms. Anomalous data may be considered suspect if no specific operational cause to invalidate the data are found. All data, valid, invalid, and suspect will be included in the final report. However, report conclusions will be based on valid data only. The reasons for excluding any data will be justified in the report. Suspect data may be included in the analyses, but may be given special treatment as specifically indicated.

All engine sensor and CEMS data will be reviewed on a daily basis including those listed below.

- Run average comparison of CEMS and PEMS data for agreement based on arithmetic mean, standard deviation, and Relative Accuracy for each measured parameter
- Daily CEMS calibration results and run-specific zero and mid-span calibration results

6.2. DATA QUALITY

As a consequence of using EPA Reference Methods to verify PEMS performance, measurement methodologies and data quality determinations are defined. In past verifications conducted by the Center and EPA’s Office of Research and Development, measurement methodologies have been selected to ensure that desired level of data quality occurs in the final results. Since sampling methods, calibration methods, and data quality checks are clearly specified in the Reference Methods, the Center's ability to change these strategies and adjust data quality is limited.

Reference Method procedures ensure that run-specific quantification of instrument and sampling system drift and bias occurs, and that runs are repeated if specific performance goals are not met. Furthermore, the Methods require adjustments be made to all measured concentrations based on run-specific measurements of instrument and sampling system response to calibration checks. Normally, measurements of these data quality indicators would be used to quantify the data quality achieved during testing, but in this case, these data are used to adjust measured values to ensure the highest possible representativeness and quality exists in the final results. Given this, the Relative Accuracy and other determinations conducted here are considered to be of acceptable quality if all Reference Method calibrations, performance checks, and concentration corrections specified in the Reference Methods have been successfully conducted. As such, the Data Quality Objective for all runs is to ensure that this has occurred. Evidence of the successful execution of these requirements will be documented in the Verification Report, along with run- and pollutant-specific calibration results.

Specific data quality indicators are discussed below including indicators for completeness, precision, and bias. These apply to all of the verification parameters that will be assessed.

A summary of the data quality indicator goals is shown in Table 5.

1. Completeness will be 100 percent for the Relative Accuracy determinations. This means that data will be collected, which meets the DQO above, for all 12 runs identified earlier in the Relative Accuracy test matrix (Table 3). The completeness goal for the off-normal engine operating tests identified in Table 4 will be 85 percent. This goal is lower than 100 percent to account for potential difficulties that may occur in (1) establishing abnormal engine operating conditions planned for this series of tests, and (2) measuring potentially large and dynamic pollutant concentration profiles in a manner that meets the DQO. Finally, the completeness goal for the sensor drift tests is 100 percent, which means that all runs will be conducted, as outlined in 4.2.2, that meet the DQO above.

2. System accuracy or bias assessments will be conducted at the beginning of each day using the protocols defined in each Reference Method. This will be accomplished by routing a suite of calibration gasses, described earlier in Section 5, directly into each monitor. For each calibration gas concentration examined, a data quality indicator goal of ± 2 percent of the analyzer span value will be used for O_2, CO_2, NO_x, and CO. A goal of ± 5 percent of the calibration gas value will be used for THC. Daily accuracy values determined from these evaluations will be reported in the final Verification Report to document the Center's ability to achieve the accuracy indicator goals specified above. These accuracys will be determined in

the field, and if deviations from the goals are observed, sampling will be halted by the Center until corrective action is taken.

3. System precision or bias will be determined for the combined sampling system and analyzer at the beginning and end of each run using the protocols defined in each Reference Method. This will be accomplished by routing zero concentration and mid-span gasses, described earlier in Section 5, through the sample collection lines and monitor systems, and comparing the measured concentrations with the certified calibration values. System bias, determined in this manner, will be measured before and after each run to determine if the run is acceptable for use. A drift of greater than ± 3 percent of analyzer span (difference between the before or after system bias) will be considered unacceptable, and the run will be repeated. If a drift of less than 3 percent occurs, which is the data quality indicator goal for precision, the average of the before and after system bias values will be used to correct the measured concentrations in each of the Methods. All system bias values and calculated drift values will be reported in the final Verification Report on a run-specific and gas specific basis as a means to document that this data quality indicator goal has been achieved.

Table 5. Data Quality Indicator Goals

Data Quality Indicator	Type of Verification Test		
	Relative Accuracy	Off-Normal Engine	Sensor-Failure
Completeness	100%	85%	100%
Precision	Drift < ± 3% of span	Drift < ± 3% of span	Drift < ± 3% of span
Accuracy	± 2% of span[a] ± 5% of cal. conc.[b]	± 2% of span[a] ± 5% of cal. conc.[b]	± 2% of span[a] ± 5% of cal. conc.[b]

a. O_2, CO_2, NO_x, and CO

7.0 VERIFICATION REPORT

7.1. OVERVIEW

A draft Verification Report will be prepared within 6 weeks of completing the field work. This report will be submitted first to ANR for review, and after modifications are made, will be submitted simultaneously to three Oil and Gas Industry Stakeholder Group representatives and the USEPA Quality Assurance Team.

The final Verification Report will contain a Verification Statement, which is a 3 to 4 page summary of the PEMS system, the test strategy used, and the verification results obtained. When the final draft is prepared, officials from USEPA's Office of Research and Development and the GHG

Center will sign the Verification Statement. The Verification Report will summarize the results obtained from the verification test, and will contain sufficient raw data to support findings and allow others to assess data trends, completeness, and quality. Clear statements will be provided which characterize the performance of the PEMS on the seven verification parameters identified earlier in Section 4.

7.2. PRELIMINARY VERIFICATION REPORT OUTLINE

Verification Statement

Section 1: Verification Test Design and Description
- Description of the ETV program
- PEMS system and site description
- Overview of the verification parameters and evaluation strategies
- Sampling and analytical procedure overview
- Quality assurance and quality control results

Section 2: Verification Results and Evaluation
- Relative accuracy determinations
- Operational performance determinations
- Other performance related findings
- Data quality assessment

Section 3: Additional Technical and Performance Data (optional) supplied by ANR Pipeline Company

References

Appendices: Raw Verification and Other Data

8.0 PROJECT ORGANIZATION AND SCHEDULE

8.1. ORGANIZATION

This Section defines project organization and key responsibilities for different organizations. The project team organization chart is presented in Figure 5. This chart identifies the functions, responsibilities, and lines of communication between the organizations and individuals associated with this verification test.

Southern Research Institute's Greenhouse Gas Technology Verification Center has overall responsibility for planning and ensuring the successful implementation of this verification test. ANR Pipeline Company is providing the PEMS technology in working order, and is providing the engine/compressor system at which all testing will be conducted. EPA's APPCD is the sponsor of this ETV Greenhouse Gas Pilot and is providing broad oversight and QA support for this verification. ANR is using a contractor, Mechanical Equipment Company of El Paso, Texas, to conduct the on-site monitoring needed to install and parameterize the PEMS. The Center is contracting with an independent testing company, Kilkelly Environmental Associates (KEA) of Raleigh, North Carolina, to provide on-site monitoring services for the verification.

ANR and the Center have signed a formal agreement (documented in the Letter of Commitment and associated documents) specifying details of financial, technical, and managerial responsibilities. These details are not repeated here.

Should a situation arise during the test that could affect the health or safety of any personnel, Brian Phillips (Field Test Leader), after consultation with the Center's on-site CEM Expert, Bill Chatterton, will have full authority to suspend testing.

8.2. SCHEDULE

Figure 6 presents the schedule of activities for verification testing of the ANR PEMS. Activities prior to the date of this plan have been completed in conformance with this schedule, and significant delays are not anticipated in completion of the remaining activities. The draft of the Verification Report is scheduled for completion and review by mid-August. The finalized report and Verification Statement will be ready for distribution by the end of September.

The July 12 start of test to be done before end of July target is significant, so as to avoid the late summer months. As ambient temperatures become higher, the engine will be limited in its ability to achieve full load operation. This is because internal combustion engines lose operating efficiency as ambient air temperature and moisture rises in the late summer months.

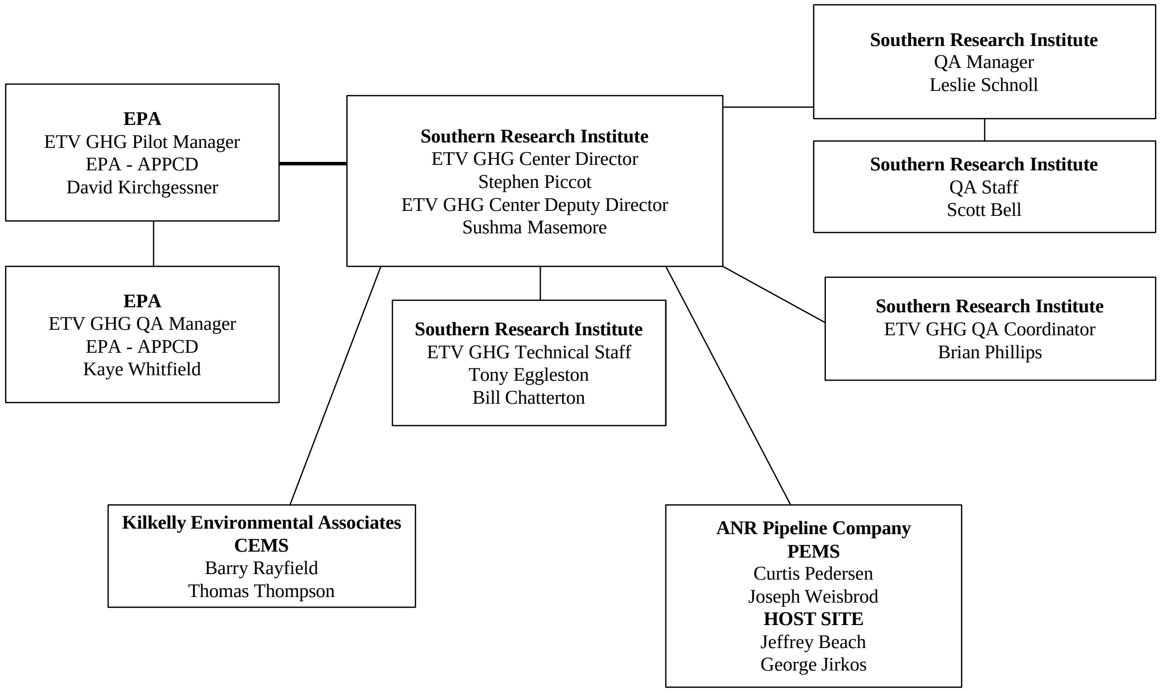


Figure 5. Project Organization

ANR and the Center will coordinate field activities such that KEA and ANR's contractor are together on-site for 1 day before testing begins. During this time simultaneous calibrations will be conducted by both firms to demonstrate comparability. SRI is coordinating with ANR to schedule verification testing of the PEMS immediately after its installation is complete.

Although not expected, delays may occur for various reasons, including mechanical failures at the site, weather, significant changes in gas demand on the pipeline, and operational issues. Should significant delays occur, the schedule will be updated and all participants will be notified.

9.0 HEALTH AND SAFETY PLAN

This Section applies to Center personnel only. Other organizations involved in the project have their own health and safety plans specific to their roles in the project.

Since the site is part of a pipeline facility, ANR's safety policies are regulated, in part by the US Department of Transportation. The Center previously provided a similar scope of work to a professional DOT compliance management company (National Compliance Services). Their assessment was that the Center's on-site job function is not covered by the Research and Special

Programs Administration, DOT Pipeline Safety Regulations requirements in 49CFR Parts 192, 193, and 195. If the scope of work changes, this determination will be re-evaluated.

SRI staff will comply with all ANR, state, local, and Federal regulations relating to safety at ANR's compressor station. This includes use of personal protective gear (e.g., flame resistant clothing, safety glasses, hearing protection, safety toe shoes) as required and completion of site safety orientation (e.g., site hazard awareness, alarms and signals).

Other than normal industrial hazards, the most significant hazard at this ANR station is the potential for explosive concentrations of natural gas. If any measurements are required inside the compressor building or any other location where hazardous levels of natural gas might accumulate, Center personnel will only use intrinsically safe apparatus. Where use of equipment not so rated is required, Center staff will not use this equipment until the area has been evaluated for gas concentration and ANR site personnel advise that it is safe to do so.

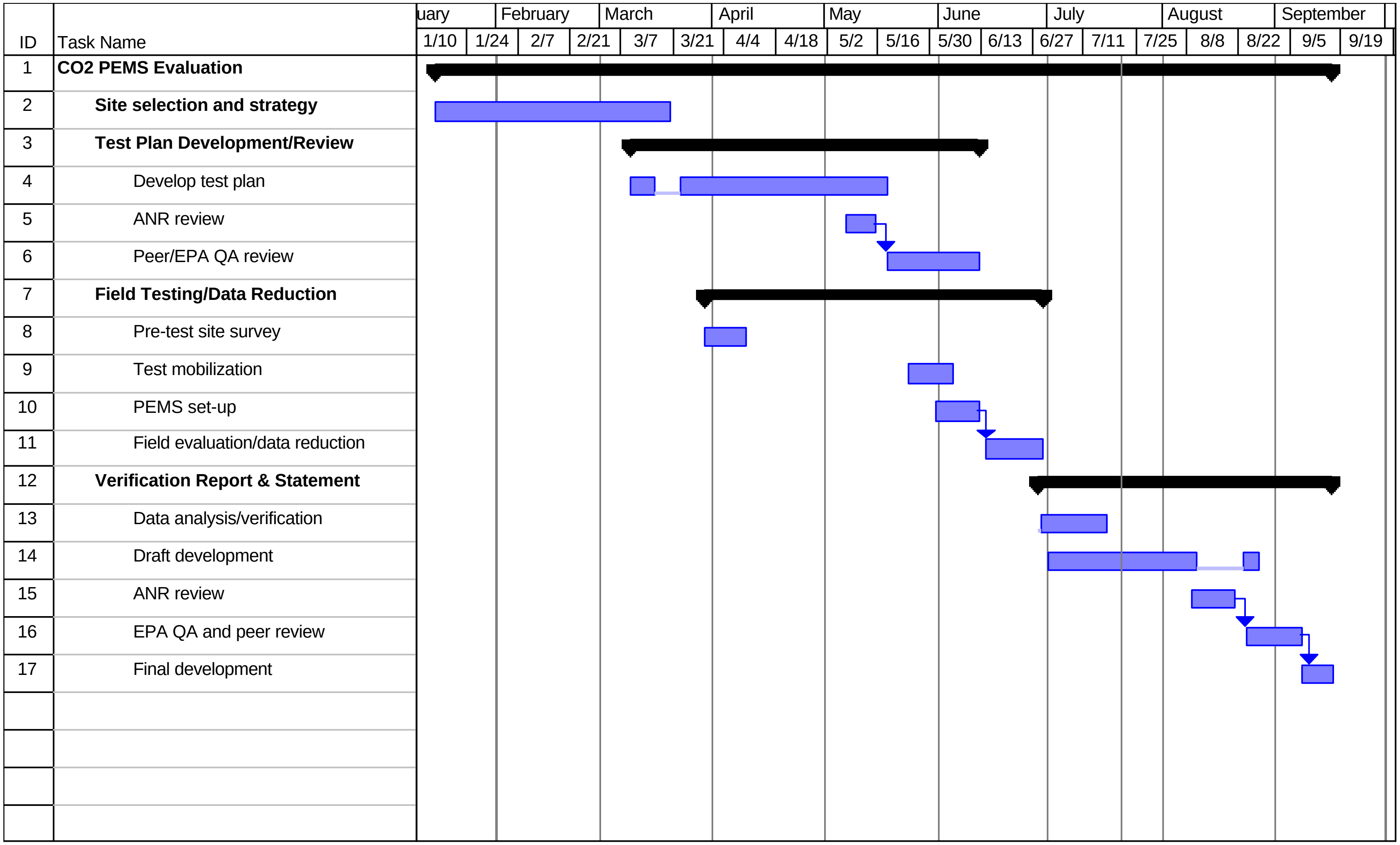


Figure 6.0 Project Schedule

10.0 BIBLIOGRAPHY

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"Example Specifications and Test Procedures for Predictive Emission Monitoring Systems." Emission Measurement Center. United States Environmental Protection Agency. Research Triangle Park, NC. 1999. Document can be obtained from the following Internet location www.epa.gov/ttn/emc/cem.html.

APPENDIX A

Field Data Log Forms
and
Data Acquisition System Outputs

FIELD DATA
LOG FORMS

PEMS INSTALLATION/SET-UP CHECKLIST

Completed by:________________________________
Date:__________

Complete Y/N/na	ACTIVITY/ITEM	REMARKS (if needed, continue on reverse side by item #)
	Software installation and checkout completed	
	Verify critical sensors – number, model	
	Sensor input present on engine computer, correct range	
	Verify and document engine I.D.	
	Verify PEMS printouts available and include identification of engine, date, time, all emission values, and alarms	

NOTES:

TESTING SET-UP/PREPARATION CHECKLIST

Completed by:________________________________
Date:__________

Complete Y/N/na	ACTIVITY/ITEM	REMARKS (if needed, continue on reverse side by item #)
	Identify test team participants and team leader	
	Identify contact person for PEMS and engine operation	
	Identify test team CEMS system – model, serial number, wet or dry basis	
	Identify operating range and calibration gasses – contents, concentrations, cylinder s/n calibration certificate	
	Verify interference tests documented or completed	
	Verify and document results of NO_2 to NO conversion test	
	Verify DAS printout is complete	
	Verify stratification testing and document results	
	Verify integrity of the sampling system, multi-point sampling, and document location of calibration gas injection	
	Document system leak check	

NOTES:

TESTING SET-UP/PREPARATION CHECKLIST
(con't)

Complete Y/N/na	ACTIVITY/ITEM	REMARKS (if needed, continue on reverse side by item #)
	Document system response times	
	Manually check DAS calculations	
	Document any data points requiring manual data collection and transfer list to "Test Run Observation Checklist"	

NOTES:

TEST RUN OBSERVATION CHECKLIST

(Note: Complete a checklist for each test run)

Completed by:________________________________

Date:__________

Complete Y/N/na	**ACTIVITY/ITEM**	**REMARKS (if needed, continue on reverse side by item #)**
	Document planned test conditions (from test matrix)	
	Pre-test calibrations on CEMS completed? Documented?	
	Atmospheric conditions	Temperature__________ Barometric Press._________ RH _________ Wind speed/direction________/________
	Start time for test run	Test Start__________
	Document actual test conditions	
	Verify PEMS and CEMS are collecting required data points	
	Verify all manually collected data are documented	
	End time for test run	Test end__________
	Post-test calibration of CEMS completed	
	Bias determined and applied to data	

NOTES:

TEST RUN OBSERVATION CHECKLIST
(con't)

Complete Y/N/na	ACTIVITY/ITEM	REMARKS (if needed, continue on reverse side by item #)
	Copy of CEMS test run data obtained Verify completeness	
	Copy of PEMS test run data obtained Verify completeness	
	Document all anomalies and unexpected events/conditions	
	DAS output obtained?	
	Obtain gas composition data from ANR?	

NOTES:

SAMPLE
REFERENCE METHOD
DATA ACQUISITION SYSTEM
OUTPUTS

PLANT NAME:
UNIT #:
LOCATION:
DATE:

	RUN #	START TIME	END TIME	REFERENCE METHOD ppmd NOx	REFERENCE METHOD %w CO2	REFERENCE METHOD lb NOx/mmBtu	CONTINUOUS MONITORING ppmd NOx	CONTINUOUS MONITORING %w CO2	CONTINUOUS MONITORING lb NOx/mmBtu	DIFFERENCE ppmd NOx	DIFFERENCE %w CO2	DIFFERENCE lb NOx/mmBtu
	1	0:00	0:30	268.80	13.28	0.435	265.05	13.08	0.436	3.75	0.20	-0.001
	2	12:01	12:31	274.23	13.34	0.442	264.45	13.05	0.436	9.78	0.29	0.006
	3	12:47	13:17	279.63	13.21	0.455	261.90	13.03	0.432	17.73	0.18	0.023
	4	13:30	14:00	275.21	13.35	0.443	264.50	13.03	0.436	10.71	0.32	0.007
	5	14:15	14:45	272.02	13.27	0.441	262.85	12.97	0.436	9.17	0.30	0.005
	6	15:00	15:30	272.58	13.27	0.441	259.75	13.03	0.428	12.83	0.24	0.013
	7	15:45	16:15	268.34	13.25	0.435	253.40	12.94	0.421	14.94	0.31	0.014
	8	16:30	17:00	271.52	13.28	0.439	254.50	12.94	0.423	17.02	0.34	0.016
	9	17:30	18:00	268.61	13.28	0.435	252.75	12.99	0.418	15.86	0.29	0.017
*	10											
*	11											
*	12											
			Test Mean:	272.33	13.28	0.441	259.91	13.01	0.430			

	ppmd NOx	%w CO2	lb NOx/mmBtu
MEAN DIFFERENCE:	12.42	0.27	0.01
STANDARD DEVIATION:	4.52	0.06	0.01
CONFIDENCE COEFFICIENT:	3.47	0.04	0.01
RELATIVE ACCURACY (%):	5.84	2.39	3.81
BIAS ADJUSTMENT FACTOR:			1.026
T - VALUE:			2.306

NOx Conversion Factor: 1.194E-07 lb NOx / SCF - ppm NOx
Fc - Factor: 1800 SCF / mmBtu

Bias Adjustment Factor = $(1 + \bar{d} / CEM)$

WHERE: $\bar{d}$ = Mean of the Differences
CEM = Mean of the Source Monitor's Data Values

* Run not included in Relative Accuracy Calculations

Reference Method Values Corrected for Bias & Drift

PLANT NAME:
UNIT #:
RUN #:
START TIME:
END TIME: DATE:

CAL GAS VALUE		INITIAL CAL	FINAL CAL	AVERAGE CAL
0.00	ppm SO_2	4.15	2.69	3.42
443.00	ppm SO_2	435.41	439.80	437.61
0.00	ppm NO_x	1.22	0.73	0.98
463.60	ppm NO_x	437.36	439.80	438.58
0.00	% O_2	0.18	0.43	0.31
12.12	% O_2	12.15	12.27	12.21
0.00	% CO_2	0.15	-0.05	0.05
11.50	% CO_2	11.38	11.48	11.43

Raw Data:	223.11	ppm SO_2
	257.27	ppm NO_x
	6.41	% O_2
	13.19	% CO_2
	0.000	% H_2O

CORRECTED VALUES:	224.15	ppmw SO_2
	271.52	ppmw NO_x
	13.28	%w CO_2
	0.439	lb NO_x / mmBtu
	6.22	%d O_2
	13.28	%d CO_2

CONVERSION FACTORS:

NO_x = 1.194E-07 lb NO_x / SCF - ppm NO_x

Fc - FACTOR = 1800 SCF / mmBtu

SAMPLE CALCULATIONS:

CORRECTED VALUES = $C_{ma} * (\bar{C} - C_o) / (C_m - C_o)$

WHERE: $\bar{C}$ = MEAN REFERENCE MEASUREMENT

C_o = MEAN ZERO CALIBRATION RESPONSE

C_m = MEAN MID OR UPSCALE CALIBRATION RESPONSE

C_{ma} = ACTUAL MID OR UPSCALE CAL GAS CONCENTRATI

EMISSION RATE = (ppm)(Conversion Factor)(Fc-Factor)(100 / % CO_2)

System Bias & Drift Calculations

PLANT NAME:
UNIT #:
RUN #:
START TIME:
END TIME:

DATE:

ANALYZER SPAN: 1000.00 ppm SO_2
1000.00 ppm NO_x
25.00 % O_2
20.00 % CO_2

; VALUE	CAL ERROR RESPONSE	CAL ERROR (% OF SPAN)	INITIAL SYSTEM BIAS CHECK RESPONSE	INITIAL SYSTEM BIAS CHECK (% BIAS)	FINAL SYSTEM BIAS CHECK RESPONSE	FINAL SYSTEM BIAS CHECK (% BIAS)	DRIFT (% OF SPAN)
ppm SO2	1.10	-0.11	4.15	0.31	2.69	0.16	-0.15
ppm SO2	451.53	-0.85	435.41	-1.61	439.80	-1.17	0.44
ppm SO2	956.04	0.01					
ppm NOx	0.73	-0.07	1.22	0.05	0.73	0.00	-0.05
ppm NOx	468.13	-0.45	437.36	-3.08	439.80	-2.83	0.24
ppm NOx	860.81	0.00					
% O2	-0.18	0.72	0.18	1.44	0.43	2.44	1.00
% O2	12.15	-0.12	12.15	0.00	12.27	0.48	0.48
% O2	20.70	-0.24					
% CO2	0.05	-0.25	0.15	0.50	-0.05	-0.50	-1.00
% CO2	11.67	-0.85	11.38	-1.45	11.48	-0.95	0.50
% CO2	17.53	-0.15					

'ION ERROR = ((R-A) / S) * 100 WHERE: R = CALIBRATION GAS VALUE
A = REFERENCE ANALYZER RESPONSE
S = ANALYZER SPAN VALUE

3IAS = ((C - A) / S) * 100 WHERE: C = SYSTEM CAL RESPONSE
A = ANALYZER CAL RESPONSE
S = ANALYZER SPAN VALUE

(Cf - Ci) / S) * 100 WHERE: Cf = FINAL SYSTEM CAL RESPONSE
Ci = INITIAL SYSTEM CAL RESPONSE
S = ANALYZER SPAN VALUE

Volumetric Flow Rate Determination

PLANT NAME:
UNIT #:
RUN #:
START TIME:
END TIME:
DATE:

TEST DATA

Test Point	Delta P (in H2O)	Temperature (Deg. F)
A-1	0.530	126
A-2	0.520	126
A-3	0.530	127
A-4	0.490	129
A-5	0.530	128
A-6	0.520	128
A-7	0.500	123
A-8	0.450	125
B-1	0.530	128
B-2	0.530	129
B-3	0.520	128
B-4	0.470	125
B-5	0.540	125
B-6	0.520	125
B-7	0.510	125
B-8	0.440	125
MAX.	0.540	129
MIN.	0.440	123

Stack Diameter (D):	367.00	inches
Stack Area (A):	105,784	sq. inches
Barometric Pressure (Pbar):	29.70	inches Hg
Static Pressure (Pg):	-0.480	inches H2O
Percent O2 (% O2):	6.22	% O2
Percent CO2 (% CO2):	13.28	% CO2
Percent Nitrogen (% N2):	80.50	% N2
Pitot Tube Coefficient (Cp):	0.84	
Meter Box Delta H (dH):	1.94	
Meter Box Factor (Y):	0.9800	
Average Meter Temp. (Tm):	67.300	degrees F
Gas Meter Volume (Vm):	23.838	cubic feet
Impinger (V):	62	ml
Silica Gel (W):	3.6	grams
Root Mean Sq. Delta P (Pavg):	0.5077	inches H2O
Mean Stack Temperature (Ts):	126.38	degrees F

CALCULATIONS

Vm(std) = (Vm)(Y)(17.64((Pbar)/(Tm + 460))	Vm(std) =	23.211	dscf
Vwc(std) = (V)(.04707) + (W)(.04715)	Vwc(std) =	3.0834	cubic ft.
% H2O = [Vwc(std) / (Vwc(std) + Vm(std))] x 100	% H2O =	11.726	% H2O
Mfd = 1 - (%H2O / 100)	Mfd =	0.883	
Ps = Pbar + (Pg / 13.6)	Ps =	29.665	in. Hg
Md = 0.44(% CO2) + 0.32(% O2) + 0.28(% N2)	Md =	30.374	lb/lb-mole
Ms = (Md)(Mfd) + 0.18(% H2O)	Ms =	28.931	lb/lb-mole
Vs = 85.49 (Cp) x SQRT[(Pavg)(Ts + 460) / (Ps)(Ms)]	Vs =	42.29	ft/sec
Qsd = (60 / 144)(Mfd)(Vs)(A)(Ps / Pstd)(Tstd / (Ts + 460))	Qsd =	1.469E+ 06	DSCFM
Qs = (3600 / 144)(Vs)(A)(Ps / Pstd)(Tstd / (Ts + 460))	Qs =	9.985E+ 07	SCFH
Qaw = (60 / 144)(Vs)(A)	Qaw =	1.864E+ 06	ACFM
		1664.1	Kscfm

ENGINE SYSTEM

DATA ACQUISITION SYSTEM OUTPUTS

	A	B	C	D	E	F	G	H
1	NOx ppm 2500 FS	CO ppm	THC ppm	% O2	% CO2	PEMS NOx gr/BHP-hr	PEMS NOx lb/hr	PEMS CO gr/BHP-hr
	0.00	0.00	1320.00	11.96	5.72	[redacted]	[redacted]	[redacted]
2	PEMS CO lbs/hr	PEMS THC gr/BHP-hr	PEMS THC lbs/hr	AIR FUEL DEVIATION PSI	Right Bank Air Man. PSI	Left Bank Air Man. PSI	Right Bank Air Man. °F	Left Bank Air Man °F
	[redacted]	[redacted]	[redacted]	-0.21	19.73	19.74	117.7	117.2
3	Fuel DP 01 in H2O	Fuel DP 02 in H2O	Fuel Flow MSCF/HR	Engine Fuel Effic %	Exh. Temp. Stand. Dev °F	Engine Speed RPM	Engine Power BHP	Engine Torque %
	75.99	75.81	43.97	100.0	17.4	350	5957	99.43
4	RELITIVE HUMIDITY	AMBIENT TEMP.	% ERROR PM-RM NOx gr/BHP-hr	RM NOx gr/BHP-hr	RM CO gr/BHP-hr	RM THC gr/BHP-hr	Average LB-RB AMP PSI	Average LB-RB AMT °F
	59	84	100.00	0.00	0.00	3.74	19.73	117.5
5	WEATHER CONDITIONS	% ERROR PM-RM CO gr/BHP-hr	% ERROR PM-RM THC gr/BHP-hr	RM/PEMS COMPARISON gr/BH-hr	NOx Comparison gr/BHP-hr	CO Comparison gr/BHP-hr	THC Comparison gr/BHP-hr	CO2 PPM Rate PEMS
		[redacted]	[redacted]					0.000
6	Ignition Timing Deg	Ign. Time Deviation Deg	Air Man Cntl SetPt PSI	Air Man Cntl Fdbck PSI	BRAKE SPEC FUEL BTU/BHP-hr	ENGINE PERF GROUP	EMIS. PERF GROUP	AMP Comparison
	12.99	-0.40	19.60	19.71	6781			

Page 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 Scanning...

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